V. Scholarship

A. Nature and Significance of the Scholarship

Impact on the field

Charlotte Elster has been active in several areas of Theoretical Nuclear Physics with special attention to the strong interaction between nucleons and nuclei. From the beginning of her research career she focused on complex problems which require sophisticated analytical and numerical techniques.

At the Institute for Theoretical Physics at the University of Bonn she was a member of the group which developed the ‘Bonn Meson Exchange Model for the Nucleon Nucleon Interaction’, which was published as an issue of Physics Reports. This ‘Bonn Potential’ is today internationally recognized as one of the best and most sophisticated descriptions of the forces between particles in a nucleus. It has been cited more than 1200 times since its appearance in 1987 and was found to be important enough to be included in two standard textbooks on ‘Introductory Nuclear Physics’. [S.S.M. Wong, ‘Introductory Nuclear Physics’, Prentice Hall, 1990; H. Frauenfelder and E.M. Henley, ‘Subatomic Physics’, Prentice Hall 1991].

Continuing her successful work on nuclear forces, she extended her research interests to few- and many-body physics and to high performance computing. Her research program has a prominent international reputation, which is easily demonstrated by the number of invited talks at major meetings, her continuous funding by the U.S. Department of Energy, periodic funding by the National Science Foundation, and her publications in the most reputable journals. A strong indicator for her scholarship is her recent election to **Fellow of the American Physical Society**. Her citation reads *‘For her significant contributions to the understanding of the nucleon-nucleon interaction and its application in few-body systems and nuclear reactions.’*

Description of the Research

In Dr. Elster’s work on the nuclear force, a force mediated by the exchange of fields or particles (mesons) in a similar fashion the electromagnetic force is mediated by the exchange of photons or light quanta. The most prominent and best known exchange particle of the nuclear force is the pion, postulated already in 1938 by Yukawa. The pion is the lightest of particles mediating the nuclear force, and its interactions with nucleons (neutrons and protons) was extensively studied in meson factories, like Los Alamos National Laboratory.

The next lightest of the exchanged mesons, about 3 times as heavy as the pion, is the eta meson. However, when comparing to the pion, the knowledge about the properties of the eta and its interaction with nucleons is quite sparse. The reason is that in contrast to the pion, the eta (and all other heavier mesons) have such a short lifetime, that it is not possible make beams for experimenting with them. Information on the interaction of the eta with nucleons has to be collected indirectly, e.g. in so-called **threshold reactions**. The term threshold reaction is coined for collisions of e.g. two protons or a photon with a deuteron, where the collision energy is large enough to produce a meson, but not too large, so that the produced meson and the other reaction partners (protons and neutrons) have small relative velocities, and thus time enough to interact with each other. A careful calculation of the process allows conclusion about the interaction of the eta meson with the nucleons. During her sabbatical at the German National Research Center Juelich, Dr. Elster got heavily involved in the physics of threshold reactions, especially with the eta-meson. She was asked to present the experimental program at the spectrometer Big Karl before an international advisory board, and was able to ensure the operation of that program for the next five years. She and her group modeled the reaction where a high-energy photon breaks up a deuteron and creates an eta-meson. From the outgoing reaction products (neutron, proton, eta) she extracted information on the interaction of the eta with the nucleons in a model independent way, and thus helped clarify some of the theoretical uncertainties inherent in the eta-nucleon interaction. She also successfully demonstrated the close connection and intertwining between reactions using electromagnetic and nucleonic probes, and thus contributes to a bridging between the two communities. A larger fraction of the proposed experiments at the Cooler Synchroton (COSY)

at the Research Center Juelich will concentrate on the threshold production of mesons, not only the eta, but also heavier mesons, and Dr. Elster will continue to give theoretical guidance to those experiments.

The wish to understand the forces between fundamental constituents is a basic goal in physics. An enormous effort, in which Dr. Elster successfully participated, has been made to understand the and model the nuclear force. The time has now come to apply those models in an environment where three or four nucleons interact with each other and thoroughly test underlying assumptions of nuclear physics. The present situation here may be seen in analogy to the helium (He) atom with two electrons interacting with each other and the nucleus, which historically played a significant role in demonstrating the validity of quantum mechanics in a system more complicated than the hydrogen (H) atom.

The vast information about the nuclear (or strong) interaction has been and still is obtained with collision experiments. Because of the short range of the nuclear interaction and thus the small distances involved, collision experiments testing the short-range part of the strong force should be carried out at higher energies. Experimental efforts at the Indiana

Cyclotron Facility (IUCF, Bloomington), the Kernfysikalische Versneller Institute (KVI, Groningen, Netherlands), COSY (Juelich, Germany) and other laboratories concentrate on probing the nuclear force in a three nucleon context to find out if the force acts only between two nucleons at a time or if there is a significant contribution of a force acting directly between three nucleons.

The determination of existence and size of possible **three-nucleon force effects** is at present one of the most important issues for understanding the nuclear force. Therefore, it is extremely important and timely to have reliable tools available to analyze and study three nucleon scattering at higher energies. In this context, reliable tools mean parameter free, *ab initio* calculations solely based on the nuclear force as input.

The development of theoretical and computational tools to study three and four nucleon scattering at higher energies has been and still is a significant part of Dr. Elster's research. New computational tools are needed because the presently available, state-of-the-art calculations of three-nucleon scattering are designed for application at lower energies. At higher energies, in the regime of current experimental interest, the description of observables as elementary as the differential cross section are unsatisfactory. Dr. Elster and her group at Ohio University developed together with W. Glöckle and his group in Bochum (Germany) new computational approaches for solving the Faddeev Equations, governing three nucleon scattering and bound states. The aim of this approach is to abandon the present, traditional methods used in three nucleon scattering and formulate, develop and implement new conceptual techniques and computational algorithms to obtain solutions for the scattering of a proton or neutron from a composite system of two (deuterium) or three (^{3}He) nucleons. This work will open the road to a new generation of exact few-nucleon calculations in nuclear physics and allow to probe the nuclear force in an energy regime that is theoretically inaccessible at present. Dr. Elster and her group have already shown that their new approach can be successfully applied when using a somewhat simple model for the nuclear force. For a two nucleon system the approach has been successfully applied for sophisticated, state-of-the-art nuclear forces, and the work on three nucleon scattering is progressing.

Dr. Elster's prior research concentrated in part on a microscopic description of the scattering of protons and neutrons from composite nuclei, ranging from the deuteron (2 nucleons) to nuclei has heavy as lead (^{208}Pb). The challenge here was two-fold: First, to obtain a clear microscopic understanding of few-nucleon systems in terms of meson exchange, second, to use these insights to understand many-body scattering phenomena. The availability of high performance computing allowed the undertaking of large scale 'first principles' calculations of nuclear reactions and test numerical predictions against today's high precision experimental observables. Dr. Elster made important improvements in the theoretical description of the collision of protons and neutrons with nuclei. She developed a procedure described in the literature by the technical term **'full-folding'**. This work became well known among the experts in this area of nuclear physics. She also developed a scheme to incorporate the effect of the struck nucleon in the nucleus into the model in a consistent fashion, which allowed her to describe experiments in an energy regime which was previously inaccessible to 'first-principles' calculations.

Within the department Dr. Elster has worked with members of the Institute of Nuclear and Particle Physics (Finlay, Rapaport, Grimes). She is the principal investigator on the new Nuclear Theory grant (Elster, Phillips, Wright), which is a combined grant of the Nuclear Theory group within the department. She also is the principal investigator of an interdisciplinary grant (Elster, Drabold, Jung, Statler) within the department for a 24 node beowulf cluster, to be shared between the computationally intense research of different physics and astronomy research areas.